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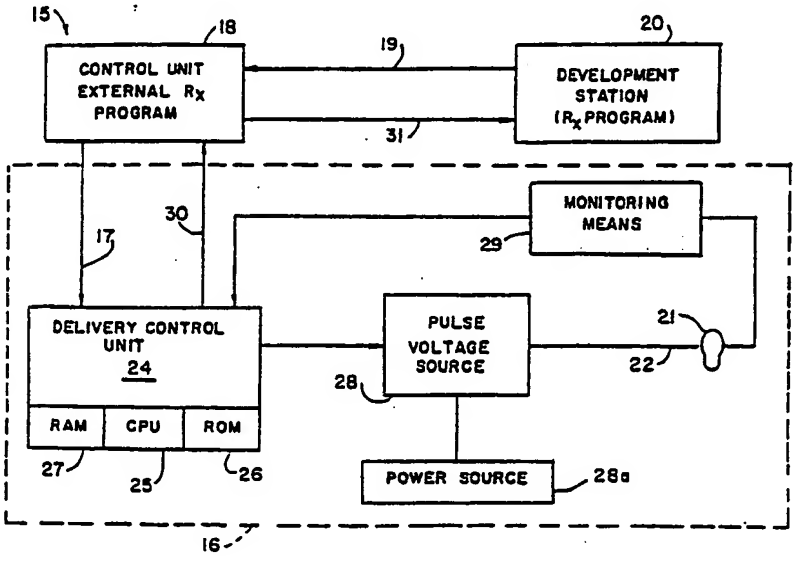

(57) Abstract

Apparatus and method of transcranial electrical nerve stimulation including the generation of a reliable, reproducible, programmable, prescriptive waveform. The applied signal has a therapeutic effect which, depending on the prescription, ameliorates pain, assists in ameliorating stress or anxiety-related disorders, minimizes the withdrawal symptoms in drug detoxification and the like. The electrical signal is a continuous and interrupted complex of pulses and has a zero net cummulative charge. The preferred application of the prescribed signal is via selected contact points on the skin of the ear. The contact points are chosen because of their known affinity for changing endogenous concentrations of neurotransmitters and neuromodulators in the brain. The parameters of the electrical prescription include current amplitude, pulse width, zero net charge delivered in any pulse, time between adjacent pulses, number of pulses in a packet, the time between adjacent packets in a pulse train and the number of pulse trains in the prescription. Monitoring of the actual delivered signal to the patient is performed. The monitored response is used to correct system output to insure adherence with the signal parameters that are prescribed to optimize accuracy of signal application and therapeutic results.

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METHOD AND APPARATUS FOR DELIVERING A PRESCRIPTIVE ELECTRICAL SIGNAL

This application is a continuation-in-part of application Serial No. 06/843,826, filed March 25, 1986, which is a continuation of application Serial No. 06/663,967, filed October 23, 1984.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to a device for providing an electrical signal to a patient. More particularly, this invention relates to a device for producing accurate, particularly complex intermittent electrical waveforms. Still more particularly, this invention relates to an apparatus of the type which comprises means for delivering a programmed prescriptive electrical signal to a patient by direct application of the prescribed signal via electrodes placed on one or more selected points of the ear or the mastoid process or, in the alternative, by radio transmission of a controlling signal to enable a radio receiver located at the point or points of application to receive the prescribed signal.

Means are provided for monitoring the signal applied to the patient and comparing it with the prescribed characteristics for noting discrepancies and correcting the applied signal. The differences noted are used to correct the original output of the delivery device. Stored data representative of the application of a signal to the patient

are analyzed and used to improve subsequent programs for application to that patient. Preferably, the signals are applied to contact points chosen because of their known affinity for changing endogenous concentrations of neurotransmitters and neuromodulators in the brain. The signals are applied and controlled as the impedance of the patient at the applied points changes during the procedure. In this respect, the patient is a conductive medium. The signal waveform parameters that are prescribed and controlled in their delivery to the patient are frequencies, positive and negative voltage amplitudes, positive and negative current amplitudes, net charge delivered in any pulse, the duration of each particular pulse, the number of pulses in each packet, the time or pauses between adjacent packets of pulses, the number of packets in each train, the time between trains of packets of pulses, and the number of trains in the prescription. Such synthesized pulses trains eliminate, to the greatest extent possible, depolarization or hyperpolarization of the nerve sheath and conditioning of the patient, while providing the maximum opportunity for accurate selectable stimulation of the communication protocols of the brain.

DESCRIPTION OF THE PRIOR ART

In the prior art, processes and devices are known for the application of electrical signals to humans for various purposes. Among these processes, transcutaneous electrical nerve stimulation (TENS) has been used for applying a signal voltage to a patient by electrodes placed at the site of local pain. In the "gate" theory of Wall and Melzack, the resulting afferent sensory signals compete with the pain signals produced by the human, resulting in analgesia.

Another type of electrical stimulation technique known to the art, referred to as percutaneous induced neurostimulation (PINS), has been used to treat intractable pain following major surgery such as spinal surgery, by the

application of electrodes implanted beneath the skin and excited by an external power source.

Still another analgesic technique involves the use of implanted deep brain probes (DBP) wherein electrodes are inserted directly into the brain so that when voltage is applied, analgesia results.

In general, the TENS and PINS processes induce essentially the same mechanism within the human organism. It is known that pain induces electrical signals which are transmitted to the brain through the spinal chord by a combination of electrical conduction and chemical diffusion where the pain signals are interpreted at the brain because of the activities they induce in certain cells. In the TENS and PINS applications, the pain signals are effectively diluted because of the competition induced with the afferent sensor signals produced by the TENS and PINS processes. The dilution of the pain signals effectively relieves the extremity of the pain interpreted by the brain.

On the other hand, the DBP process is completely different. The electrical signals applied directly to the peri-aqueductual grey space within the brain induce additional secretion of beta-endorphins which act to inhibit the reception of the pain signal at the interpretive end (the Raphe nuclear cells). In effect, the pain signal is blocked from reaching a destination within the brain where it is normally interpreted and analgesia results.

Quite clearly, the DBP processes are unsatisfactory because they require invasive techniques and are generally limited to terminal patients with extraordinary, intractable pain. It is desirable to utilize the pain relieving mechanism of the DBP process without the disadvantages of its invasive application.

Accordingly, it is a general object of this invention as described in the specification to provide a device for applying a prescription of electrical signals to a patient which stimulates the secretion of endorphins and other neurotransmitters related to induction of analgesia in a

manner similar to the DBP process. While the TENS and PINS processes are advantageous in that they are non-invasive, such processes have limited applicability because of their limited efficacy. Those processes are limited in the degree of analgesia produced, the quality of relief obtained, and the range of applicability of the processes to the broad spectrum of varieties of pain. Thus, it is another general object of this invention to provide a device for the application of such electrical signals which are effective for relieving pain for a wider range of maladies, conditions, and syndromes to a degree not heretofore known in the art.

There have also been attempts to treat stress, obesity, insomnia, and related disorders as well as to treat pain associated with withdrawal from the effect of nicotine or other addictive drugs by the use of electrical stimulation.

In this regard, significant research has been conducted by Dr. Ifor D. Capel, which shows generally that for a set of unique frequencies, the transcranial voltage induces the secretion of beta-endorphins in the brain and leads to the same kind of analgesia as DBP processes. Dr. Capel has also shown that a different set of frequencies is effective for treating the pain associated with withdrawal, as well as treating the physiological symptoms associated with withdrawal. Such efforts are the subject of co-pending United States patent application Serial No. 626,335, filed June 29, 1984, the disclosure of which is incorporated by reference.

In general, Dr. Capel has explored some effects of electrical signals on the mechanisms for neurotransmission within the brain. The effect of habituating drugs on brain chemistry and cellular activity is such that both stimulants and depressants cause debilitating effects on such neuro activity which lead to long-lasting physical change and ultimately to deterioration of the cell affected. By utilizing particularly discovered frequencies related to particular drugs, the debilitating effect can be reversed to counteract the effect of drugs at the cellular level. Thus, the application of the teachings of Dr. Capel are both

beneficial and therapeutic as an aid to recovery from addiction, from the standpoint of both relief of pain and attention to the physiological changes associated with withdrawal from the use of addictive drugs.

Thus, it is another general object of this invention to provide a device with the capability of providing prescriptive therapeutic voltage signals of duration, amplitude, frequency, pulse width, and intermittency according to the teachings of Dr. Capel, as well as to extend these teachings with the applicant's research.

A number of analog devices for producing waveforms suitable for the application of the TENS and PINS processes are known. However, such devices do not produce signals which are sufficiently reproducible, controllable and accurate to be merchandized as a reliable medical device. More critically, analog circuitry cannot match the diversity of waveforms producible with digital electronics, the facility for incorporating patient feedback to modify the signal and the speed with which these processes can be conducted using digital electronic means.

Accordingly, it is another general objective of the invention described hereinafter to provide such an instrument which uses a significantly different technology to achieve optimality in the parameters noted above, and as more fully described in the specification.

Still further, it is another general objective of this invention to utilize effectively the state of the art in digital circuitry, programming techniques, and micro-processing design to produce an instrument of the type described for use by an investigator and for application of such signals to a patient.

SUMMARY OF THE INVENTION

Directed to achieving the above-mentioned objectives and achieving the aims of the invention, a method and apparatus according to the invention comprises means for

developing and generating a reliable, reproducible, program-controlled, prescriptive electrical waveform, having a desired therapeutic and alagesic effect. The system according to the apparatus comprises a development station and a control unit for developing and storing a prescriptive waveform of the type described, available for insertion into a personal delivery instrument (PDI).

The personal delivery instrument, according to the invention, comprises means for receiving and storing the developed prescriptive waveform from the control unit for delivery of an accurately-controlled waveform to the patient. The PDI includes a central processing unit, having a ROM and a RAM for programming a voltage source powered by a battery, to provide the desired waveform transcranially to the head of a patient. Means are provided for monitoring the signal applied to the patient, comparing it with the prescribed signal characteristic stored according to the prescription from the control unit and by noting discrepancies, correcting the applied signals. The signal actually applied to the patient can be recorded. In addition, any differences from the prescription in the signal actually delivered to the patient are also recorded for subsequent use in analyzing and improving subsequent prescriptive programs for application to that patient and others. The actually delivered signal will be affected by the change over time of the impedance of the patient and, therefore, if not corrected, the applied signal will drift away from the prescriptive signal. Thus, in addition to being recorded for later study, the actually delivered signal can also be used as a feedback signal to continuously correct the signal applied to the patient back to the intended prescriptive signal.

The PDI includes components for accurately controlling each of the parameters of a train of pulses and for adjusting the signals so that the net voltage charge applied to the patient is zero. For purposes of this description, a set of pulses is referred to as a packet and a train is a

set of packets. Thus, the definition of the waveform includes:

(1) the pulse frequency or frequencies, f_i, since the prescription may include pulses delivered at more than one frequency, where f_i is the frequency of the pulses in the ith packet;

(2) the positive amplitude A_{pi} for each pulse in each packet of each train forming the prescription;

(3) the positive pulse duration S_{pi} for each pulse in each packet of each train forming the prescription;

(4) the negative pulse amplitude A_{ni} for each pulse in each packet of each train forming the prescription;

(5) the negative pulse duration S_{ni} for each pulse in each packet of each train forming the prescription;

(6) the number n_i of pulses in packet i;

(7) the time $_{(i-1)}t_i$ between packets in the train j;

(8) the number J of trains with i packets;

(9) the number N_j of packets in the train j; and

(10) the time $_{(j-1)}T_j$ between the trains in the prescription, which time may vary between respective adjacent trains during the prescription of the J number of trains.

Thus, in the generalized case, the instrument is capable of delivering a prescriptive programmed waveform defined by the set of parameters noted above, i.e.

$$R_X = (f, A_p, S_p, A_n, S_n, n_i, t_i, J, N_j, T_j).$$

In the foregoing summary, it should be noted that the prescription may include packets and pulses at different frequencies, where the packets may have different amplitudes and pulse widths. With this generalization, the instrument operates to deliver a zero net current so that within any one packet, $A_pS_p = A_nS_n$, to achieve a zero net charge. Once A_p and S_p are fixed, the product A_nS_n is fixed by independently setting A_n and S_n to meet the matching equality requirement. Secondly, the value of the current may be changed over the course of a given treatment. Experiment

has shown optimum results can be obtained with an envelope of decreasing current values.

The method according to the invention is also disclosed discussing a number of internal tests and verifications for security and monitoring.

Means are provided for delivering the signals from the PDI to the patient by leads from a machine attached to the pinnae, ear lobe, mastoid process, or to other contact points chosen because of their affinity for changing endogenous concentrations of neurotransmitters or neuromodulators.

Electrode design and placement on different parts of the ears are important features in the overall system. Placement of the electrodes so that the positive pole is on the motor-dominant side of the patient is necessary to achieve optimum result. The electrode must be sharp enough to deliver a high areal current density but not so sharp that it will penetrate the skin. The placement is critical. The electrodes must be placed in contact with points on the ears which have been tested and display locally greatest electrical conductivity, and in the general location on the ear to stimulate one of the selected major cranial nerves innervating the ears.

An alternative means for delivery, are provided by using radio transmission of the signal from a separate computerized controller-transmitter, containing the patient's program for a particular prescriptive waveform, with the reception means worn by the patient. The patient receiver will decode the signal and output the prescribed waveform.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above-recited features, advantages and objects of the invention, as well as others which will become apparent, are attained and can be understood in detail, more particular description of the invention briefly summarized above may be had by reference

to the embodiments thereof which are illustrated in the drawings, which drawings form a part of the specification. It is to be noted, however, that the appended drawings illustrate only preferred embodiments of the invention and are, therefore, not to be considered limiting of its scope for the invention may admit to other equally effective embodiments.

In the Drawings:

Fig. 1 is a block diagram of the system, including the personal delivery instrument for applying prescriptive signals transcranially to a patient according to the invention;

Fig. 2A is a generalized waveform for illustrating the parameters controlled by the device in Fig. 1 for achieving an accurate prescription for transmission to a patient and for analysis showing a typical wave packet i of pulses;

Fig. 2B is a similar generalized waveform of a typical train of packets j;

Fig. 2C shows a similar generalized waveform of a typical prescription of trains J;

Fig. 2D is a chart of the parameters of the prescription delivered by the instrument;

Fig. 3 is a more complex waveform of the type heretofore applied to a patient capable of being analyzed by the system according to the invention;

Fig. 4 is a drawing similar to Fig. 3 showing the use of the device in analyzing the waveform of the type of Fig. 3;

Fig. 5 is an exemplary program sequence for inputting the prescriptive waveform from the control unit to the PDI;

Fig. 6 is an exemplary program sequence for monitoring the prescriptive waveform delivered from the PDI to a patient;

Fig. 7 is a representative drawing showing the application of the prescriptive waveform to the Shen Men acupoint of a patient;

Figs. 8A-8C are block diagrams showing several modes of transmitting the prescriptive waveform to a patient;

Fig. 9 is a more detailed functional block diagram of the personal delivery instrument of the type shown in Fig. 1;

Fig. 10 is a more detailed functional block diagram of a controlled signal generator unit of the PDI;

Fig. 11 is a general block diagram illustrating the use of a monitor for changing the applied signal delivered to a patient;

Fig. 12 is a graph of an alternate applied signal current level as applied to a patient;

Fig. 13 is a graphical analysis of the electrochemical effects created by two different prescriptions in accordance with the present invention;

Fig. 14 is a graphical comparison of two different trains in accordance with the present invention and their resulting effects;

Fig. 15 is an application switching connection scheme for applying a prescriptive signal in an alternate process in accordance with the invention;

Fig. 16 is an alternate switching connection scheme for applying a prescriptive signal in yet another alternate process in accordance with the invention;

Fig. 17 is yet another alternate switching connection scheme for applying one or more prescriptive signals in still another alternate process in accordance with the invention; and

Fig. 18 is a block diagram of the monitoring and corrective feedback scheme for use with multiple applied prescriptive signals.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In Fig. 1, a transcranial electrical nerve stimulator device and system is generally referred to by the reference numeral 15, for developing and generating a reliable, reproducible program-controlled prescriptive electrical waveform having a therapeutic effect for amelioration of pain or assistance in ameliorating stress or anxiety related disorders and relieving drug habituation diseases by the transcranial application of the prescriptive electrical waveform to a patient. The system comprises a personal delivery instrument (PDI) 16, a control unit 18, and a development station 20. The PDI 16, when programmed with the prescriptive electrical waveform, is used to provide current signals transcranially to the head 21 of a patient either by direct connection 22, as shown in Fig. 1, or by radio transmission to a device worn by the patient or implanted in the patient as shown in Figs. 8B-8C. The control unit 18 is usable by medical personnel to program the required prescriptive signals in the PDI 16. The development station 20 is used to generate compatible data to the control unit 18 and to analyze the results from the control unit 18 and the PDI 16.

The prescriptive waveforms having the extended therapeutic effects are disclosed in detail in the above-mentioned pending patent application of Ifor D. Capel, while other signal prescriptions have been known to investigators for research on patients or animals in developing acceptable prescriptions. It is contemplated that the device according to the invention is capable of delivering any of such prescriptive waveforms to a patient, upon identification of the parameters of the waveform, including their sequence.

Starting with a developed prescriptive waveform having a desired or intended therapeutic effect for a predetermined disorder stored for retrieval in the control unit 18, or a prescriptive waveform for research, the program for that

programmed waveform is provided by connection between PDI 16 and the control unit 18 through an interfacing connection 17. The PDI 16 includes a delivery control unit 24 having a central processing unit 25, a ROM 26, and a RAM 27 for precisely programming the operation of a pulse electrical source 28 connected to a power source 28a to provide the desired waveform on a output lead 22 connected to the head of the patient.

Monitoring means 29 are provided for monitoring the signal applied to the patient and comparing it in the delivery control unit 24 with the prescribed characteristics stored therein from the control unit 18 for noting discrepancies and correcting the applied signals. The differences noted are used to correct the original signal output of the personal delivery instrument (PDI) 16 for storing data accurately representative of the actual application of a signal to the patient for analysis, to develop subsequent prescriptive programs, and to improve existing prescriptive programs for application either to that patient or others by returning the stored data on an output to the control unit 18 for interfacing on lead 31 with the development station 20. As is apparent, a developed or modified prescriptive program prepared at the development station 20 may be transferred by the interface 19 to the control unit 18, or to a plurality of such control units located at a number of locations, such as hospitals.

The control unit 18 also operates with respect to the PDI 16 to perform a number of additional functions. The control unit 18 thus may reset the PDI 16 to prepare it for reception of a new prescriptive program, interrogate for current operational conditions and errors, perform appropriate internal verifications, communicate selected applications to the PDI in simple or encrypted format, verify the correct receipt of the prescriptive program by the PDI 16, communicate a current time, a and request statistics from the PDI 16.

The PDI 16, on the other hand, after communication of a series of instructions from the control unit 18, outputs an electrical signal, the basic component of which is a pulse having a frequency, shape, duration, amplitude and number, each of which is programmable. It is a feature of the PDI to provide an output where the time average of the current passing between the two output electrodes is zero. The PDI 16 may also be programmed to provide either a low frequency or a high frequency sequence wave modulation to the output pulse, acting to turn on or off the output pulse so that the output pulse becomes a modulation envelope for the HF modulation. The presence and frequency of modulation are also programmed into the device 16, as is the time to traverse from zero to nominal amplitude (i.e., ramp time).

The system 15 has the advantage of using currently available devices. For example, for the PDI, a 146805 CMOS microcomputer may comprise the CPU 25, interacting (acting as a signal source) with a byte wide CMOS RAM 27 and EPROM 26, a programmable D/A converter with low power operational amplifiers to generate the output signal, and CMOS LSI logic. The control unit 18, for compatibility, may utilize a 16 bit computer with floppy discs to store the program sequence parameters to insure media compatibility with the development station 20. The development station may comprise a personal computer compatible with accompanying accessories for utilizing stock software readily available for laboratory analysis and report generation.

A significant feature of the invention resides in its precise control of each of the particular parameters of a wave train applied to a patient according to the prescription.

Figs. 2A-2D illustrate a generalized depiction of an electrical waveform for analyzing a train of pulses comprising a plurality of irregularly spaced packets of pulses wherein the pulses in each packet are also controlled. Thus, the PDI 16 includes a pulse profile controller which

produces a waveform, the components of which are shown respectively in Figs. 2A, 2B and 2C.

As shown in Fig. 2A, a typical wave packet i of pulses at a frequency f_i are shown having a positive amplitude A_p, a negative amplitude A_n, a positive pulse duration S_p, and a negative pulse duration S_n, for a representative example of a packet i, for the three pulses shown (n_i=3). It should be noted that the pulse frequency f_i may vary either within a packet i or between adjacent packets so that the prescriptive waveform includes a specification of the pulse frequency or frequencies f_i, where f_i is the frequency of the pulses in the i packet.

For a packet i of pulses at a frequency f_i, the PDI 16 delivers a pulse having a positive pulse amplitude A_{pi} for each pulse in each packet of each train forming the prescription. While Fig. 2A shows positive and negative pulses A_p, A_n, of approximately the same respective amplitudes, the amplitudes may vary between adjacent positive or negative pulses if the prescription so requires. Similarly, the PDI 16 produces a waveform which includes a specification of the positive pulse duration S_{pi} for each pulse in each packet of each train forming the prescription, and the negative pulse duration S_{ni} for each pulse in each packet of each train forming the prescription, and the negative pulse duration S_{ni} for each pulse in each packet of each train forming the prescription, as well as the number of pulses in each packet, n_i.

As shown in Fig. 2B, the PDI 16 also delivers a train j of packets i of pulses of the type shown in Fig. 2A. The PDI 16 thus also controls the respective times between the delivery of adjacent packets where the time between the first packet and the second packet, for example, is noted by $_1t_2$ so that for a generalized case, the instrument delivers packets at the time $_{(i-1)}t_i$ for packet i.

As shown in Fig. 2C, the instrument 16 also delivers a prescription of trains J of packets i where the time between adjacent trains is controlled according to the generalized

expression $_{(j-1)}T_j$, where the time between respective adjacent trains during the prescription by vary. For the generalized prescription chart shown in Fig. 2D, the entire prescription includes M trains and N packets in the prescriptive train j. Thus, in the generalized case, the instrument is capable of delivering a prescriptive program waveform defined by the parameters shown in Fig. 2D under the conditions wherein the product A_pS_p is equal to A_nS_n to deliver a zero net charge.

Such synthesized pulse trains eliminate to the extent possible a polarization demyelination of the nerve sheath of the patient, conditioning the patient, and provide the investigator the maximum opportunity for accurate simulation of the communication protocols of the brain of the patient.

Fig. 3 is a more complex waveform which may also be analyzed according to the application of the techniques of the invention. Because the prior art devices for applying TENS signals to patients tended to output a signal like that shown in Fig. 3, this particular waveform is of special interest to investigators.

Such a waveform 33 can be analyzed by the instrument of the invention by inputting it or a reproduction of the waveform to the monitoring means 29 to produce a program for determining by approximation its constituents as shown in Fig. 4. Thus, the investigator has a common basis for comparison of new prescriptions with former applications.

Fig. 5 is a program for transferring the signal prescription from the control unit 18 to the PDI 16. For security, the patient identification, such as name and code number, is input to the control until 18 and a brief description and other identifying data concerning the patient profile are input in steps 36 and 37. The patient code is checked for accuracy against a user identification for security in step 39 and, if incorrect, the prescription will not be loaded from the control unit 18 into the PDI 16 and the program returns to the input step 36. If correct, the treatment code is input in sequence 38 containing the

prescription for a precise wave train to be applied to the patient. As will be seen, more than one prescription is provided by sequentially inputting the frequency, the amplitude A_p, of the positive pulse, the sequence S_{pi} of the positive pulse, the amplitude A_{ni} of the negative pulse, and the duration S_{ni} of the negative pulse in steps 40, 41, 42, 43 and 44. Thereafter, in steps 45, the product of $A_{pi}S_{pi}$ is calculated and the product $A_{ni}S_{ni}$ is calculated, the calculated products are compared to provide a net zero current, and a correction signal is input in step 45a. Thereafter, the number n_i of pulses in each packet, the number of packets N in the train, the time between packets, the time between trains, and the number of trains in the prescription, along with any other necessary parameters and any additional prescriptions for treatment of the patient in steps 46 to 52 so that at step 53 the overall voltage prescription has been input to the PDI 16. An appropriate final check may be made at step 52 to insure complete delivery of all prescriptive components, if desired.

Fig. 6 is a block diagram of a representative sequence for checking and correcting the prescriptive delivery. After the device is connected to the patient and appropriate connection confirmed in step 55 and the master clock started in step 56, the system commanded in step 57 to perform a sequence of internal delivery service checks of the battery in sequence 58, of the RAM in sequence 59, of any other appropriate components 59a, and of the circuit by monitoring the circuit using test voltages in step 60. Step 55 may include checks on whether the electrodes are open, loose or closed, station power delivery is appropriate, and other preliminary confirmation tests. Performance outside of predetermined parameters in any of these steps 57-59a inaugurates a corresponding notice signal 58b, 59b, 60b to signal operator attention in step 61. If the internal delivery service checks are accurate and within accepted norms, the prescriptive wave train stored in accordance with Fig. 5 is initiated in step 62 and the delivery of that

prescription is monitored at predetermined intervals by sequentially interrogating at intervals Q the components of the system in steps 70-74, followed by a clock test in step 75 whereupon a command is given to go to the next packet or train of pulses. If any of the parameters is outside of accepted norms, a correction signal is given and the zero level reset (for zero net charge) is also periodically provided, preferably after each pulse, especially for low frequency transmission. If the signals are within accepted norms, the delivered data to the patient are then recorded for subsequent transfer to he control unit 18 and for use at the development station 20 for analysis.

Fig. 7 shows a portion of the ear of a patient illustrating the application of the electrodes 22 to selected contact points on the ear of a patient. In the past, electrical signals or other processes were delivered to a patient by direct application of the prescribed voltage through electrodes placed on selected elements of the ear or the mastoid process. Preferably, the precisely controlled prescriptive electrical signals according to the invention are applied to selected points of the ear having optimal conductivity. These contact points are chosen because of their known affinity for changing endogenous concentrations of neurotransmitters or neuromodulators in the brain. The application of the prescriptive signals at these points optimizes the impedance match between the output of the system 15 and the patient as a conductive medium.

Figs. 8A-8C show alternative modes for providing the prescriptive electrical signal to a patient without direct connection to the unit as at lead 22 in Fig. 1. Thus, Fig. 8A contemplates a delivery control unit 24' miniaturized to be worn by the patient or further miniaturized to become a part of a non-invasive application appearing similar to a hearing aid or eyeglasses with enlarged ear lobes. In this embodiment, the control unit 18', similar to control unit 18, is connected to a RF transmitter 102 for transmitting all of the signals for loading and applying the prescriptive

waveforms to the unit for reception by an RF receiver 104 connected to the delivery control unit 24'. Thus, when all of the components of the delivery control unit 24' are in chip form, the delivery control unit 24' may be loaded and the prescriptive electrical signal delivered at the patient. Such radio transmission may require additional security coding to prevent erasing a preloaded delivery control unit 24'. In a simpler embodiment, the delivery control unit 24' may comprise a cassette or cartridge preloaded with the prescriptive electrical signal from a control unit 18' to be activated by a secured RF transmitted signal. Either of the foregoing embodiments permits a patient significant increase in freedom of movement while undergoing treatment.

Fig. 8B is representative of an embodiment wherein a control unit 18' and a delivery control unit 24' operate as described in connection with Fig. 1 but where the prescriptive waveform is transmitted by an RF transmitter 102' to be received by an RF receiver 104' at the patient in a suitable patient device 105, such an ear piece or radio receiver.

In either of the embodiments of Figs. 8A and 8B, where monitoring is desired as discussed in connection with Fig. 1, the RF transmitter/receiver pair may comprise a pair of transceivers suitably secured for two-way communication of the transmitted and monitored data.

Fig. 8C is similar to Fig. 8B wherein the patient device is an implant 105a to illustrate an embodiment wherein the prescriptive waveform is radio transmitted to an implanted receiver at the patient to achieve the desired therapeutic effects.

Fig. 9 is a functional block diagram of the PDI 16 according to its presently preferred embodiment for incorporation in a portable desk top unit. However, the principles of the invention may be embodied in a device sized to be protable with the patient as in Figs. 8A-8C while receiving the applied signal characteristics, such as discussed in connection with such illustrations.

The embodiment of Fig. 9 is designed to provide the electrical signal characteristics of the type described, the power requirements, memory requirements, display, key board, connectors and operational requirements to achieve the intended purposes of the invention. The output current pulse characteristics provided by the unit include a zero cumulative current with a positive 35 milliamp peak output current programmable throughout the range of zero to maximum current with limitations on the maximum output current for patient safety. The frequencies of the pulses are provided in a range of 0.5 hz to 500 hz with a one percent deviation or less from optimum throughout the range of primary interest in implementing the waveform prescription according to the aforementioned identified patent application of Ifor D. Capel. The frequency range and pulse shape are programmable and provided with a 100 microsecond sampling interval, fr example. Where wave modulation is necessary or desirable, the modulating wave may be provided in a suitable range, for example, 5.0 Khz to 100 Khz for high frequency modulation, whereas low frequency modulation of the output current pulse is selectable in predetermined time increments, such as 0.1 minutes, up to 20 minutes, on an on/off basis. Preferably, the ramp time exhibited by the wave pulses (i.e., the time lapse necessary to change from zero to the programmed output current) is typically 100 microseconds.

The unit is designed to meet load characteristics approximately 200,000 ohms in parallel with a 0.10 microfarad capacitance. The unit is preferably powered by an internal dual power supply having a battery and a backup to insure data retention in the case of power failure. A data retention feature is also provided as will be discussed. Preferably, the internal clock is accurate to 0.1 percent. The display is preferably a one digit LED display capable of generating numbers zero to nine while the keyboard is preferably a one button unit. The speaker, for emitting audible warning signals, may generate audio signals as desired, for example, form two seconds to five minute

increments. Connections of the PDI 16 to the patient are provided by conventional plugs and jacks and, as described, the unit is capable of a self-test sequence, a main line sequence, and data monitoring storage sequencing. As described, the unit is capable of generating current pulses of defined amplitude and duration, with high frequency and low frequency modulation ranging from .05 hz to 500 hz according to the program stored therein according to the waveform prescription discussed in connection with Figs. 2A-2C and 5. The self-diagnostic sequence for the unit has been discussed in connection with Fig. 6. Preferably, the unit is intended for operation over a five hour period so that current pulses on the order of or less than 25 micro-amperes provided to a 200,000 ohms load require a 0.1 watt signal (because of the unique parameters of the waveforms) permitting selection of a battery source to meet the operating parameters.

Thus, as shown in Fig. 9, the PDI 16 comprises a plurality of functional modules. The controller 80 provides for the timing and control of all of the units and acts as an interface between any two modules. The display numeric module 81 is used as a status indicator, while the keyboard module 82 is used to command data input to inaugurate the program sequence described in connection with Fig. 5. The alarm module 83 may be actuated as described in connection with Fig. 6 to obtain operator attention, as described in connection with step 61. Thus, the alarm module not only functions as an alarm, but also monitors the time between activities and the starting and stopping time to associate the data generation with the status of the patient. The program storage module 84 and the data storage module 85 respectively store the electrical signal prescription and self-test schedule in the program storage module 84 as well as the results of the tests and signal schedule in the data storage module 85.

The battery indicator module 86 monitors the conditions of the battery source in the system to provide an indication

when the battery needs charging, while the Input/Output port module 87 outputs the gathered data and receives the inputs of the new program sequences. The signal generator module 87 generates the electrical signal prescription with the signal duration and waveform created according to the discussions of Figs. 1 and 3 by the program sequence. Thus, the PDI as shown in Fig. 9 is capable of performing program scheduling, signal generation, self-testing, data output, and battery charging or changing. Each of these modes have been described in connection with Figs. 1-8C above.

In particular, the controller 80 may control an 8 bit CMOS microcomputer of a single chip design to permit signal generation at random time intervals and to interface between different modules. Thus, the controller 80 may include the CPU, ROM, and RAM capabilities discussed in connection with Fig. 1.

The display module 81 preferably comprises an LCD character generator driven by a 4 bit word from the microprocessor in the controller 80. That signal is converted to proper format and multiplexed to drive the LCD, as is known in the art. A 32 Khz clock is used to drive the generator. The clock chip preferably contains an on-chip oscillator to generate the multilevel waveforms.

The signal generator module 87 is shown in greater detail in Fig. 10. The signal generator comprises an 8 bit D to A converter 90 to obtain the needed voltage levels, connected to operational amplifiers 91. The microprocessor in the controller 80 will program the D to A unit 90 to provide current at the desired levels. The output levels from the D to A converters is thus fed into the two operational amplifiers to generate a electrical differential at the output. By adjusting the binary number into the D to A converter 90 from the master control unit 80, a bipolar signal from the operational amplifiers can generate current flowing in either direction through the electrodes 22, connected to terminals E1 and E2. The binary numbers are selected to generate the pulse or inverse current signal

with an 8 bit resolution. As discussed above, the microprocessor control unit selects the binary number determined by the software.

Input/output module 87 controls all of the input and output activity of the PDI. Thus, the output comprises a plurality of signal channels for output of status information and input of programming sequencing, two of which are dedicated to the use of electrodes and another of which is for recharging, if a recharge cable battery is selected.

Referring now to Fig. 11, a simplified block diagram of an apparatus for delivering a prescriptive signal to a human patient 100 is shown. The system comprises generally a control computer 102 and a delivery system 104, both of which can be substantially identical to similar devices previously described. Monitor 106 shown in Fig. 11 is connected to contact points of the patient so as to actually monitor a plurality of the parameters of the signal as they are applied to the patient. Specifically, the voltage, current and frequency parameters are monitored. As mentioned above, one preferred frequency is approximately 10 Hz, the preferred voltage is in the range of 1 to 4 volts and the current is in the size range of approximately 10-15 microamperes. It has been discovered that the impedance of the patient will change over a period of time during the treatment application of the prescriptive signal. It is important to maintain the precise value of the parameters which are delivered to the patient, particularly the current parameter. Therefore, each of the three most sensitive parameters mentioned above are monitored and fed back to control computer 102 so that the delivery system adjusts the signal applied to the patient to be in accordance with the prescription.

It has been further discovered in performing research using the apparatus, that treatment can be optimized by applying waveforms at correct frequencies that are initially delivered at around 15 microamperes. When this amplitude is gradually decreased to approximately 6 microamperes over the

course of a 40 minute treatment period, the resulting effects are optimized for the entire period. Therefore, Fig. 12 illustrates that the current level is reduced from a maximum at the onset of treatment to a minimum at the end of the treatment. The feedback mechanism of voltage, current and frequency which was discussed with reference to Fig. 11 are compatible to support the application of current at at the reduction level over a period of time.

A typical number of pulses in a packet is 256. The typical positive cycle of the pulse is about six times the amplitude of the negative cycle of the pulse. The durations of the cycles are reversed so that $A_pS_p=A_nS_n$, as previously discussed. This yields a zero net charge for an entire pulse.

With the pulse configurations established as above, it has been discovered that different frequencies induce different behavioral and biochemical effects generally from patient to patient. It has also been discovered that each frequency or repetition rate of pulses relates favorably to a unique ratio of pulses per packet and pauses between packets to achieve optimal results. Referring to Figs. 13 and 14, please note that a packet of a burst of pulses all of the same width, exhibiting a zero net charge characteristic and constant in frequency as previously described differs in making an effect on the patient merely because the pauses between packets in the train are different. This is illustrated for achieving a first effect and a second effect as shown in Fig. 14. Fig. 13 illustrates that a prescription with shorter pauses between packets will excite the beta endorphins to a greater level than a prescription with greater pauses between identical packets. On the other hand, the adrenocortico trophid hormone (ACTH) is excited in reverse.

It has further been discovered that electrode design has progressed to the point where molds can be made of the contour of the individual patient's pinnae. Contact electrodes are embedded in the molds with locations that

correspond to the contact point or points on the skin of the ear that show the greatest electrical conductivity. These points as previously mentioned are those points selected because of their known affinity for changing the endogenous concentrations of neurotransmitters and neuromodulators in the brain. The molds can be removed and reinserted many times and the electrodes will return to the correct contact point positions. Molds can be made to accommodate multiple electrodes to access more than one contact point simultaneously, if desired.

Experiments have further shown that the same electrical prescription applied to different points on the ears will produce different chemical and behavioral effects. Additionally, different frequencies applied to different points produce distinguishable differences. Prescriptions have been individualized to provide appropriate therapy for different conditions. For example, the prescription for chronic pain due to arthritis is different in both electrical content and electrode application than the prescription to assist patients in the withdrawal from smoking. As shown in Fig. 15, a given prescription A 108 can be applied through switch 110 so as to be applied to a first pair of contact points 112 to achieve a first effect or alternately to a second pair of contact points 114 for accomplishing a desired second effect.

Fig. 16 illustrates the capability of switching between a prescription A having a first pulse frequency provided by memory device 116 and a second prescription B having a pulse frequency at a second frequency stored in a control device 118. Prescription A for causing a first effect can be applied through switch 120 to a first pair of contact points or alternately through switch 120 to a second pair of contact points to cause a second effect on the patient. In similar fashion, prescription B can be selected from device 118 through switch 122 to be applied to the first pair of contact points or alternately to the second pair of contact points. Hence, a total of four effects can be obtained by

the use of the devices in connections illustrated. If desired, switches 120 and 122 can be electronic switches that cycle on a time shared basis between the two positions with each set of contacts at the respective switches.

Hence, generally, to accommodate delivery of different electrical signals to different contact point pairs, the prescription delivery system is desirably capable of generating each different waveform, outputting them to the appropriate electrode pair and monitoring the output so as to maintain the parameters within the limits of accuracy required. Generally, therefore, the simplified block diagram shown in Fig. 17 accomplishes this. The prescription delivery system 124 produces up to four different electrical prescriptions through an appropriate switching combination 126 so as to apply the prescriptions simultaneously or in sequence to four electrode pairs 128. Each of these electrode pairs is appropriately monitored by monitoring device 130, the output of which is fed back to the prescription delivery system.

Fig. 18 illustrates the effect of the feedback mechanism for correcting the signals delivered to the patient. Storing means 130, including controlling means 132, is connected to the delivery means 134, including at least two signal sources 136 and 138. As mentioned above, it is common for there to be up to four signal sources in an actual delivering means 134. The output from signal source 136 and signal source 138 are initially determined by the prescriptive input from controlling means 132 which is applied to patient 140. The output from the patient is detected by voltage, current, frequency (V,I,F) monitor 142 for the first signal and by V,I,F monitor 144 for the second signal. The feedback from these respective monitors are applied to comparison means 146 and 148, respectively, in the delivering means. The output from the comparison means is applied to a correcting means 152 and 154, respectively, for modifying the output signals from signal sources 136 and 138, respectively. Hence, each of the prescriptions is

delivered to the patient within the prescribed parameters of the prescription at all times.

The invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the claims rather than by the foregoing description and all changes which come within the meaning and range of the equivalents of the claims are therefore intended to be embraced therein.

WHAT IS CLAIMED IS:

1. An apparatus for delivering a predetermined, pre-programmed prescriptive signal waveform to a living being, comprising:

storing means pre-programmable with a predetermined prescriptive signal from an external source, said prescriptive signal containing a predetermined prescription of parameters of said signal suitable for stimulating the neurochemistry of the brain;

delivering means connected to said storing means for delivering said prescriptive signals to said living being upon command; and

means for monitoring the delivered prescriptive signal to produce a signal sequence thereof with respect to the predetermined prescriptive signal.

2. The apparatus as set forth in claim 1, wherein said delivering means includes

a signal source for producing an electrical signal to said living being according to predetermined prescription parameters, and

wherein

said prescriptive signal storing means includes means for controlling said signal source to maintain the precision of the electrical signal from said source.

3. The apparatus as set forth in claim 2, wherein said delivering means includes a comparison means for comparing said signal sequence from said monitoring means with said stored pre-programmed prescriptive signal and correcting means for said delivered signal when one or more selected parameters of the delivered signal is outside of any of the

predetermined limits referenced in the stored program for said one or more selected parameters.

4. The apparatus as set forth in claim 3, wherein said predetermined pre-programmed prescriptive signal includes parameter values for output voltage, current and pulse frequency, said monitoring means separately monitors the parameters of output voltage, current and pulse frequency delivered to said living being and produces feedback outputs relating to said comparison means, said correcting means correct said delivered signal to conformance thereof with said predetermined pre-programmed prescriptive signal as changes occur in the impedance of said living being.

5. The apparatus as set forth in claim 4, wherein said predetermined prescriptive signal includes a first signal portion and a second signal portion having at least one parameter value different from said first signal portion, said signal source includes a first source portion for providing a first electrical signal to said living being according to said first signal portion of said pre-determined prescriptive signal and a second electrical signal to said living being according to said second signal portion of said predetermined prescriptive signal, said monitoring means includes separate means for monitoring said first signal portion and said second signal portion, and

said correcting means including separate connecting portions respectively connected to said separate monitoring portions to respectively assure conformance of said first electrical signal with said first prescriptive signal portion and said second electrical signal with said second prescriptive signal portion.

6. The apparatus as set forth in claim 5, wherein said delivery means includes

a first set of contact points for receiving said first electrical signal, said first set of contract points touching the skin of said living being at a first location, and

a second set of contact points for receiving said second electrical signal, said second set of the contact points touching the skin of said living being at a second location.

7. The apparatus as set forth in claim 5, wherein said delivering means includes

a first set of contact points for receiving at least one of said first electrical signal, one of said first set of contact points touching the skins of said living being at a first location in or about the first ear and the other of said first contact points touching the skin of said living being at a corresponding first location in or about the second ear,

a second set of contact points for receiving at least one of said first electrical signal and said second electrical signal, one of said second set of contact points touching the skin of said living being at a second location in or about the first each and the other of said second contact points touching the skin of said living being at a corresponding second location in or about the second ear,,

a first mold customized to fit the first ear of said living being fixedly embedding the first one of said first set of contact points and the first one of said second set of contact points so as to reliably determine their locations when said first mold is worn by the living being and

a second mold customized to fit the second ear of said living being fixedly embedding the second one of said second set of contact points and the second one of said second set of contact points so as to reliably determine their location when said second mold is worn by the living being.

8. The apparatus as set forth in claim 4, wherein the current delivered to said living being decrease in level from about 15 microamperes to about 6 microamperes over a period of time of about 40 minutes.

9. The apparatus as set forth in claim 1, wherein said predetermined, pre-programmed prescription signal from the external source stored in said receiving and storing means is stored in terms of parameter instructions specifying the

amplitude A_p of a positive pulse in a packet i, the duration S_n of said negative pulse, said delivering means including means for assuring that the respective products A_pS_p and A_nS_n of the prescriptive signal to said living being are equal so that a zero net charge is delivered to the living being in any pulse.

10. The apparatus as set forth in claim 1, and including receiving means for receiving the pre-programmable prescriptive signal from the external source and applying it to said storing means.

11. The apparatus as set forth in claim 1, and including communications means for communicating the prescriptive signal from the external source to the storing means.

12. The apparatus as set forth in claim 1, and including communications means connected to said delivering means for communicating said prescriptive signal to said living being.

13. The apparatus as set forth in claim 1, wherein said predetermined, pre-programmed prescription signal from the external source stored in said receiving and storing means is stored in terms of parameter instructions, prescription R_x determining said prescription signal being defined by parameters where:

f = frequency;
A_p = the voltage amplitude of the positive pulse;
S_p = the duration of each positive pulse;
A_n = the voltage amplitude of each negative pulse;
S_n = the duration of each negative pulse;
n = the number of pulses in a packet;
t = the time between packets in a train;
j = the number of trains with packets;
N = the number of packets in a train; and
T = the time between trains.

14. The apparatus as set forth in claim 1, wherein said delivering means includes means for directly applying said signals transcranially to a living being.

15. The apparatus as set forth in claim 14, wherein said living being is a human being and said transcranially applying means includes means for applying said signals to contact points on the skin of said human being which are determined to offer optimum electrical conductivity.

16. The apparatus as set forth in claim 15, wherein said delivering means includes means for transmitting said signals and receiving means, including a contact device worn by said human being, for receiving said signals.

17. The apparatus as set forth in claim 16, wherein said patient device is an earpiece.

18. The apparatus as set forth in claim 16, wherein said patient device is an implant.

19. The apparatus as set forth in claim 1, wherein said monitoring means includes means for delivering a waveform to said storing means for analysis.

20. The apparatus as set forth in claim 19, wherein
said storing means includes a central processing unit having a RAM and a ROM for storing instructions to produce said prescriptive signal,
said delivering means includes a battery and a signal source connected to said battery, and
said storing means controlling said signal source and said battery to produce said prescriptive signal for delivery.

21. The apparatus as set forth in claim 20, wherein said receiving and storing means stores said prescriptive

programming and includes a control unit operably programmably controlling said delivering means.

22. The apparatus as set forth in claim 21, wherein the control unit includes means for correcting the delivered prescriptive signal in accordance with the waveform from said monitoring means.

23. The apparatus as set forth in claim 1, wherein said signal delivering means includes means for applying said signal to a location on the skin of said living being which provides optimal electrical conductivity and impedance matching with neural networks of the living being.

24. The apparatus as set forth in claim 1, wherein said delivering means includes means for testing selected parameters of said prescriptive signal at predetermined intervals to determine whether said parameters are within accepted limits for those selected parameters respectively.

25. The apparatus as set forth in claim 24, wherein said delivering means further includes means for commanding a correction for those selected parameters which are outside of accepted limits.

26. An apparatus for delivering a programmed prescriptive signal waveform to a living being, comprising:

means for receiving from an external source a programmed prescriptive signal waveform; and

means for delivering said programmed prescriptive signal waveform to a living being upon command, said delivering means including means for generating said programmed prescriptive signal waveform in the form of an electrical waveform for electrochemically altering the neurochemistry in the brain comprising a train of packets of pulses, said train of

packet of pulses including specifications for the frequency f_i of the pulses in a packet i forming the prescription; the positive amplitude A_{pi} for each pulse in each packet of each train forming the prescription; the positive pulse duration S_{pi} for each pulse in each packet of each train forming the prescription; the negative pulse amplitude A_{ni} for each pulse in each packet in each train forming the prescription; the negative pulse duration S_{ni} for each pulse in each packet in each train forming the prescription; the number n_i of pulses in packet i; the time $(i-1)t_i$ between packets in a train j; the number j of trains, each of which has i packets; the number N_j of packets in train j; and the time T_j between trains i and j in the prescription.

27. The apparatus as set forth in claim 26, wherein said generating means delivers pulses at different frequencies.

28. The apparatus as set forth in claim 26, wherein said generating means delivers said pulses at differing amplitudes and pulse widths.

29. The apparatus as set forth in claim 26, wherein said generating means for delivering said pulses delivers to said living being a zero net current, so that within any one packet A_pS_p equals A_nS_n.

30. The apparatus as set forth in claim 29, wherein said apparatus includes means for independently setting A_nS_n once A_p and S_p are fixed to meet the condition specified.

31. In an apparatus for applying electrical signals to a living being of the type which will, depending on the

frequencies and methods of application, cause changes in neurochemicals so as to ameliorate pain, assist in ameliorating stress or other anxiety related disorders, or assist in chemical detoxification from harmful drugs, said signals comprising an ideal sequence of electrical waveforms, the improvement comprising:

means adapted to connect to a living being for delivering said signals comprising a continuous series of intermittent series of pulses at predetermined frequencies for electrochemically altering the neurochemistry in the brain and spinal chord of said living being for maximum effect by applying said signals at contact points on the skin which provide optimal impedance matching with neural networks of the living being.

32. A method of applying an electrical signal transcranially, comprising the steps of:

providing a prescriptive program of electrical signals comprising an interrupted complex of pulse trains; and

delivering said prescriptive program of electrical signals to a living being by applying said signals to contact points on the skin at constant current levels which have been found through experiment to induce optimal change in the neurochemical composition in the brain and brain stem.

33. A method of applying an electrical signal transcranially, comprising the steps of :

providing a prescriptive program of electrical signals in the form of a complex of pulse trains including packets of pulses and pauses between packets, said pulses in each of said

packets having a zero net charge delivered to said human being, and

delivering said prescriptive program of electrical signals to a living being by applying said signals to contact points on the skin at gradually decreasing current levels which have been found through experiment to induce optimal change in the neurochemical composition in the brain and brain stem.

34. The method as set forth in claim 33, wherein the signals to the living being are decreased over a treatment duration of about 40 minutes.

35. The method as set forth in claim 34, wherein the signals to the living being are delivered initially at about 15 microamperes and decrease to a value of about 6 microamperes.

36. The method as set forth in claim 33, wherein said prescriptive program includes a first complex of pulse trains having pulses at a first frequency intended to cause a first predetermined biochemical effect and a second complex of pulse trains having pulses at a second frequency intended to cause a second predetermined biochemical effect.

37. A method for delivering a prescriptive electrical waveform to a living being, comprising the steps of:

storing for delivery a program of an electrical waveform defined by the parameters of its positive pulse amplitude A_p, positive pulse duration S_p, negative pulse amplitude A_n, and negative pulse duration S_n;

calculating the product of A_p and S_p;

calculating the product of A_n and S_n;

comparing the respective calculated products;

setting the products equal to each other by

adjusting at least one of the parameters A_p, S_p, A_n, S_n, so that a zero net charge is delivered to said living being; and

delivering the prescriptive electrical wave form to said living being.

38. The method as set forth in claim 37, wherein the step of setting includes the step of adjusting A_n or S_n for a given A_p and S_p so that the respective products are equal.

39. A method for delivering a pre-programmed prescriptive electrical signal defined by its parameters, comprising the steps of:

inputting each of the parameters into a delivery control unit;

delivering an output electrical signal to a living being according to the parameters inputted into said control unit; and

monitoring the delivered electrical signal for comparison of the parameters of the delivered electrical signal with the parameters of the prescriptive electrical signal input to the delivery control unit.

40. The method as set forth in claim 39, wherein the step of inputting includes the steps of

inputting parameters comprising a positive pulse amplitude of A_p and a positive duration S_p;

calculating the product of A_p and S_p;

inputting a negative pulse amplitude A_n and a negative pulse duration S_n;

calculating the product of A_n and S_n;

comparing the respective calculated products; and

adjusting at least of the parameter so that the calculated products are equal to each other.

41. The method as set forth in claim 40 further including testing the prescriptive waveform when stored in said delivery control unit to determine whether a selected one or more of said parameters are within predetermined limits.

42. The method as set forth in claim 40, further including testing the prescriptive waveform when delivered from said delivery control unit to determine whether a selected one or more of said parameters are within predetermined limits.

43. The method as set forth in claim 42, further including the steps of commanding a correction for each tested parameter outside of said predetermined limits.

44. The method as set forth in claim 41 further including the steps of commanding a correction for each tested parameter outside of said predetermined limits.

45. The method as set forth in claim 39, wherein the steps of inputting each of the parameters includes the steps of inputting each of the following parameters f, A_p, S_p, A_n, S_n, n, t, j, N and T, wherein

f = frequency;
A_p = the voltage amplitude of the positive pulse;
S_p = the duration of each positive pulse;
A_n = the voltage amplitude of each negative pulse;
S_n = the duration of each negative pulse;
n = the number of pulses in a packet;
t = the time between packets in a train;
j = the number of trains with packets;
N = the number of packets in a train; and
T = the time between trains.

46. The method as set forth in claim 39, wherein the step of delivering includes the step of controlling a battery-powered voltage source to deliver said electrical

signal optimally having the prescriptive electrical waveform.

47. The method as set forth in claim 39, wherein the step of delivering includes the steps of applying said output electrical signal transcranially to a living being.

48. The method as set forth in claim 47, wherein the step of applying includes the step of determining the area on the skin of a living being which provides optimal conductivity and the step of applying the output electrical signal to said area.

49. The method as set forth in claim 39, wherein the step of delivering includes the steps of transmitting said output electrical signal and receiving the same at the situs of a living being.

50. An apparatus for delivering a programmed prescriptive signal waveform to a living being, comprising

storing and controlling means for receiving from an

external source a programmed prescription of parameters to cause a predeterminable biochemical effect, said parameters in said prescription including

a predetermined number of trains of packets of pulses,

a predetermined number of packets in each of said trains,

a predetermined pause duration between packets in each of said trains,

a predetermined number of positive voltage pulses in each of said packets,

a predetermined number of negative voltage pulses in each of said packets,

a predetermined amplitude and duration for

each of said positive voltage pulses,

a predetermined amplitude and duration for each of said negative voltage pulses,

a predetermined frequency for the positive voltage pulses and the negative voltage pulses in each of said packets, and

a predetermined current value for each of said trains; and

means activated by said storing and controlling means for delivering an electrical signal waveform of said programmed prescription to a living being upon command for electrochemically altering the neurochemistry in the brain by causing said predetermined biochemical effect.

51. The apparatus as set forth in claim 50, wherein said delivering means includes

a first set of contact points touching the skin of said living human being at a first location,

a second set of contact points for touching the skin of said living being at a second location,

and

switching means connected to selectably switchably apply said electrical signal waveform to said first contact points and said second contact points.

52. The apparatus as set forth in claim 50, wherein said prescription includes at least two trains differing in at least one of said prescription parameters.

53. The apparatus as set forth in claim 52, wherein the two trains differ in the parameter of said predetermined frequency.

54. The apparatus as set forth in claim 53, wherein the two trains differ in parameters of said predetermined number of positive voltage pulses, predetermined number of negative voltage pulses and predetermined pause duration between packets.

55. The apparatus as set forth in claim 50, wherein said positive voltage pulses and said negative voltage pulses produce a net zero voltage for each packet of pulses.

56. The apparatus as set forth in claim 55, wherein the predetermined amplitude of each of said negative pulses differs from the predetermined amplitude of each of said positive pulses, the product of the predetermined amplitude and duration of each of said positive pulses equalling the product of the predetermined amplitude and duration of each of said negative pulses.

57. The apparatus as set forth in claim 50, wherein said storing and controlling means is suitable for receiving a second programmed prescription of the same parameters as included in said first-named programmed prescription to cause a second predetermined biochemical effect, said delivering means activated by said storing and controlling means upon command for selectably delivering said first-named electrical signal waveform of said first-named programmed prescription and a second electrical signal waveform of said second programmed prescription.

58. The apparatus as set forth in claim 57, wherein said delivery means include a first set of contact points for delivery of said first-named electrical signal waveform and a second set of contact points for delivery of said second electrical signal waveform.

59. The apparatus as set forth in claim 58, wherein said first-named electrical signal is produced at a first time

and said second electrical signal is produced at a second time, and including switching means for selectively switching said first set of contact points to receive said first-named electrical signal waveform at said first time while disconnecting said second set of contact points therefrom and switching said second set of contact points to receive said second electrical signal waveform at said second time while disconnecting said first set of contact points therefrom.

60. The apparatus as set forth in claim 50, wherein said predetermined positive and negative voltage levels are prescribed to gradually decrease over the length of said programmed prescription.

61. The method of delivering a programmed prescriptive signal waveform to a living being, comprising the steps of:

providing a prescriptive program of electrical signals to cause a predeterminable biochemical effect, said prescriptive program comprising a plurality of separate parameters including

a predetermined number to trains of packets of pulses,

a predetermined number of packets in each of said trains,

a predetermined pause duration between packets in each of said trains,

a predetermined number of positive voltage pulses in each of said packets,

a predetermined number of negative voltage pulses in each of said packets,

a predetermined amplitude and duration for each of said positive voltage pulses,

a predetermined amplitude and duration for each of said negative voltage pulses,

a predetermined frequency for the positive

voltage pulses and the negative voltage pulses in each of said packets, and

a predetermined current value for each of said trains; and

transcranially delivering said prescriptive program of electrical signals to the living being by applying said signals to contact points on the skin.

62. The method as set forth in claim 61, wherein

the prescriptive program of electrical signals to cause a first predeterminable biochemical effect has a first predetermined relationship between said predetermined frequency for said first effect and the number of positive voltage pulses and negative voltage pulses in a packet thereof and a second predetermined relationship between said predetermined frequency therefor and the pause duration between packets thereof, and

the prescriptive program of electrical signals to cause a second predeterminable biochemical effect has a third predetermined relationship between said predetermined frequency for said second effect and the number of positive voltage pulses and negative voltage pulses in a packet thereof, and a fourth predetermined relationship between said predetermined frequency therefor and the pause duration between packets thereof.

FIG. 1

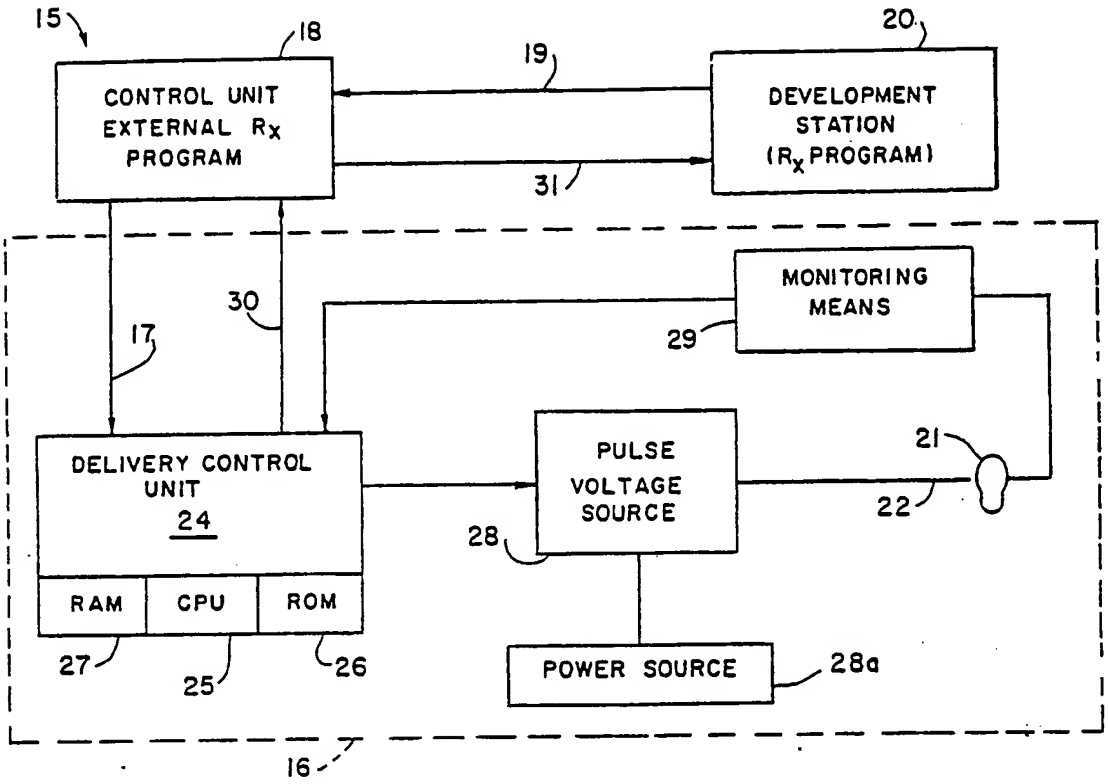
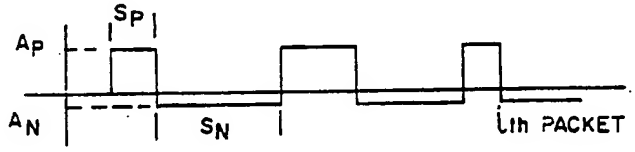
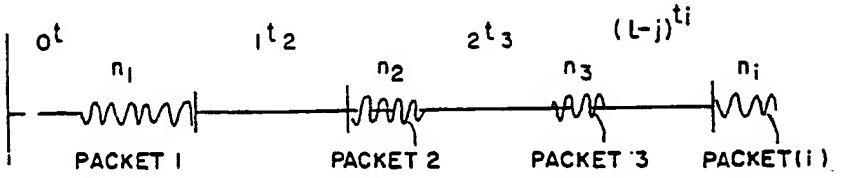


FIG. 2A



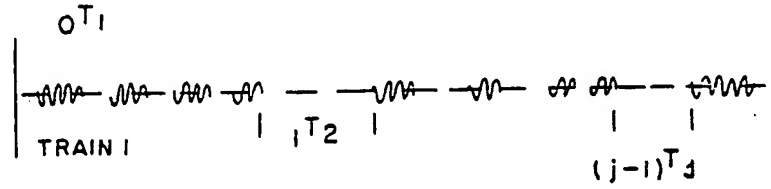
TYPICAL WAVE PACKET OF PULSES ^{fi}
(FOR EXAMPLE n=3)

FIG. 2B



TYPICAL TRAIN OF PACKETS
TRAIN j

FIG. 2C



TYPICAL Rx OF TRAINS

FIG. 2D

R_X

	λ	1	2	3	.....	I
(1)	f	f_1	f_2	f_3	.....	f_i
(2)	A_P	A_{P_1}	A_{P_2}	A_{P_3}	.....	A_{P_i}
(3)	S_P	S_{P_1}	S_{P_2}	S_{P_3}	.....	S_{P_λ}
(4)	A_N	A_{N_1}	A_{N_2}	A_{N_3}	.....	A_{N_λ}
(5)	S_N	S_{N_1}	S_{N_2}	S_{N_3}	.....	S_{N_λ}
(6)	n	n_1	n_2	n_3	.....	n_λ
(7)	t	${}_0t_1, {}_1t_2$	${}_2t_3$	${}_3t_4$	.....	t_{λ} (λ-1)
(8)	j	1	2	3	.....	J
(9)	N	N_1	N_2	N_3	.....	N_j
(10)	T	${}_0T_1, {}_1T_2$	${}_2T_3$	${}_3T_4$	.....	${}_{j-1}T_j$

$R_X = (f_i, AP, SP, AN, SN, n_i, t_i, J, N_j, T_j)$

$A_P S_P = AN\,SN$

FIG. 3

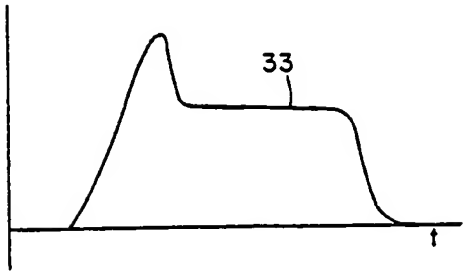
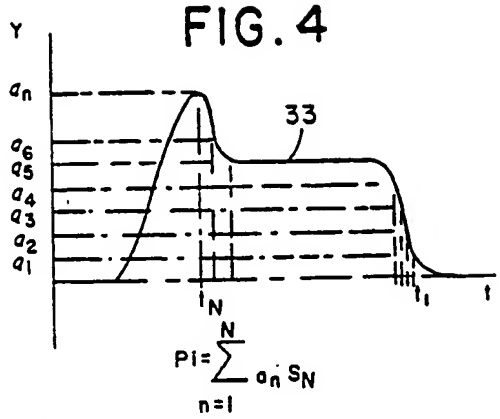


FIG. 4



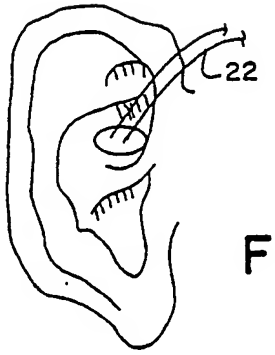


FIG. 7

FIG. 8A

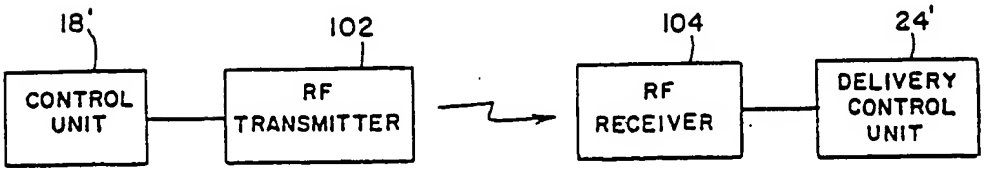


FIG. 8B

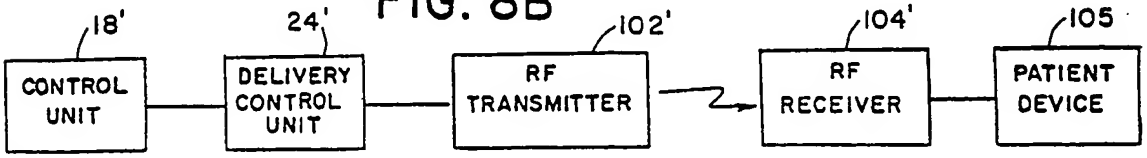
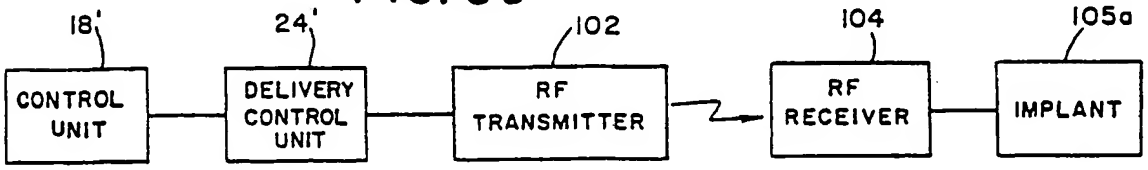


FIG. 8C



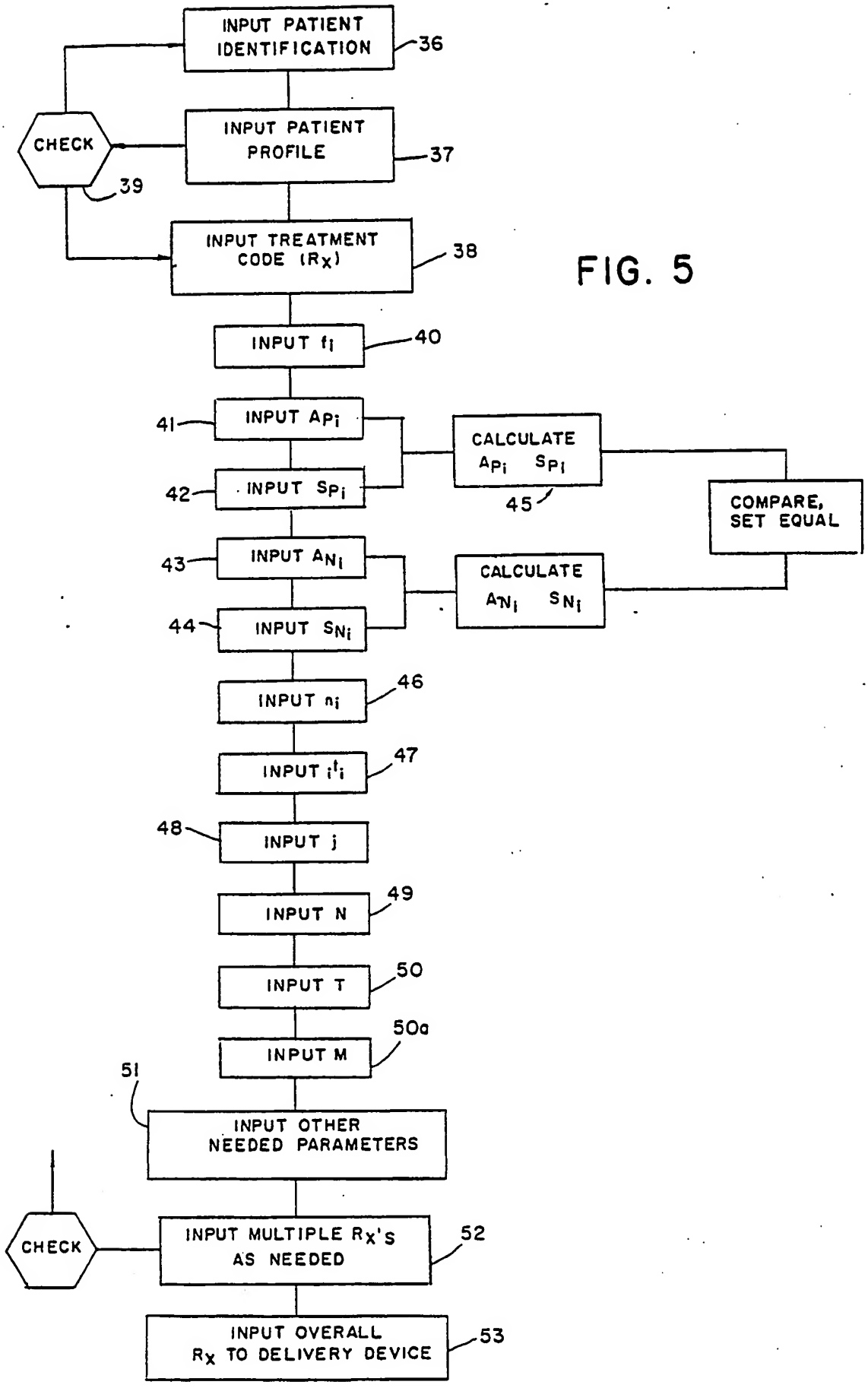

INPUT PATIENT IDENTIFICATION
36
CHECK
INPUT PATIENT PROFILE
37
39
INPUT TREATMENT CODE (R_X)
38
INPUT f_i
40
41
INPUT A_{Pi}
CALCULATE A_{Pi} S_{Pi}
42
INPUT S_{Pi}
45
COMPARE, SET EQUAL
43
INPUT A_{Ni}
CALCULATE A_{Ni} S_{Ni}
44
INPUT S_{Ni}
INPUT n_i
46
INPUT i^{t}_{i}
47
48
INPUT j
INPUT N
49
INPUT T
50
INPUT M
50a
51
INPUT OTHER NEEDED PARAMETERS
CHECK
INPUT MULTIPLE R_X'S AS NEEDED
52
INPUT OVERALL R_X TO DELIVERY DEVICE
53

FIG. 5

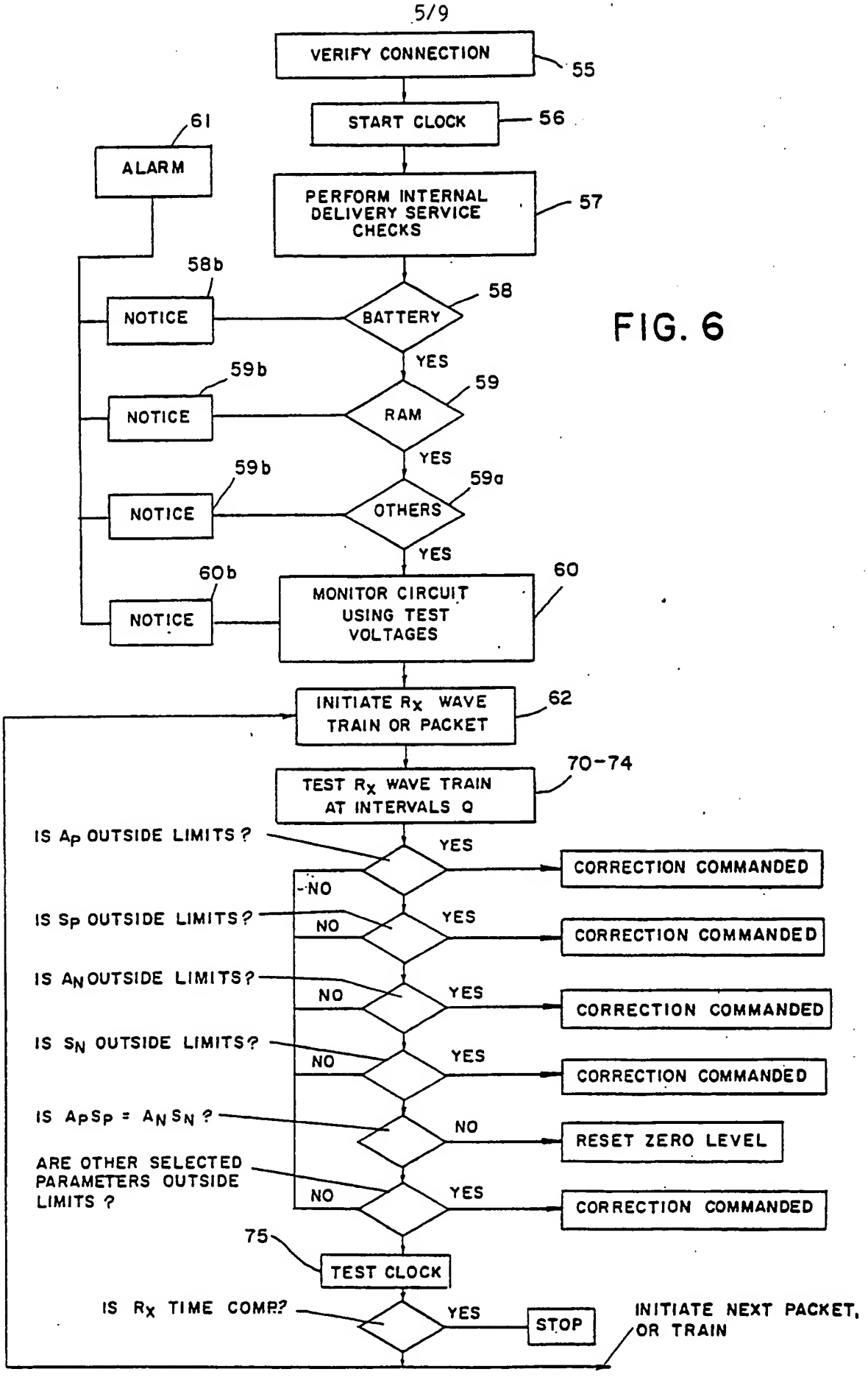

VERIFY CONNECTION
55
START CLOCK
56
61
ALARM
PERFORM INTERNAL DELIVERY SERVICE CHECKS
57
58b
NOTICE
BATTERY
58
YES
59b
NOTICE
RAM
59
YES
59b
NOTICE
OTHERS
59a
YES
60b
NOTICE
MONITOR CIRCUIT USING TEST VOLTAGES
60
INITIATE Rx WAVE TRAIN OR PACKET
62
TEST Rx WAVE TRAIN AT INTERVALS Q
70-74
IS Ap OUTSIDE LIMITS ?
YES
CORRECTION COMMANDED
NO
IS Sp OUTSIDE LIMITS?
NO
YES
CORRECTION COMMANDED
IS AN OUTSIDE LIMITS?
NO
YES
CORRECTION COMMANDED
IS SN OUTSIDE LIMITS?
NO
YES
CORRECTION COMMANDED
IS ApSp = AN SN ?
NO
RESET ZERO LEVEL
ARE OTHER SELECTED PARAMETERS OUTSIDE LIMITS ?
NO
YES
CORRECTION COMMANDED
75
TEST CLOCK
IS Rx TIME COMP?
YES
STOP
INITIATE NEXT PACKET, OR TRAIN

FIG. 6

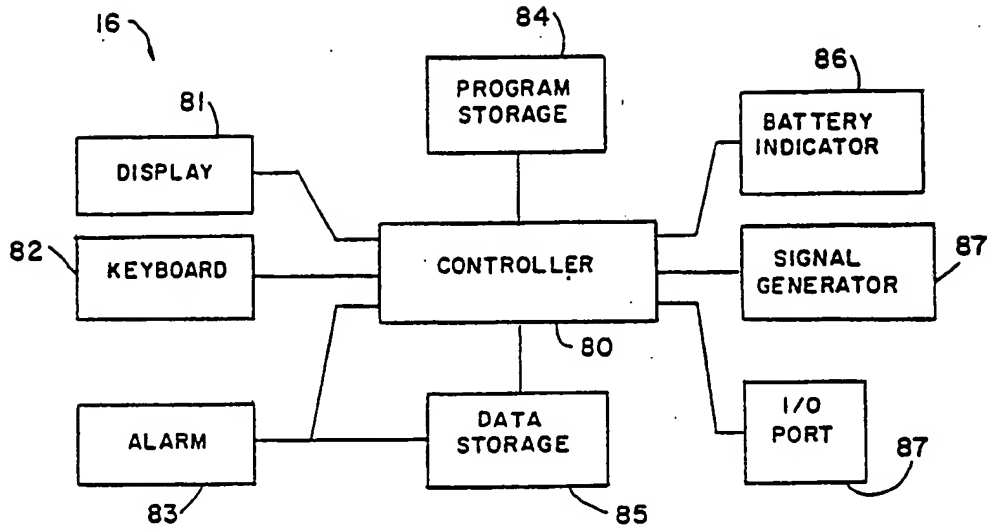

16
84
PROGRAM STORAGE
86
BATTERY INDICATOR
81
DISPLAY
82
KEYBOARD
CONTROLLER
SIGNAL GENERATOR
87
80
ALARM
DATA STORAGE
I/O PORT
87
83
85

FIG. 9

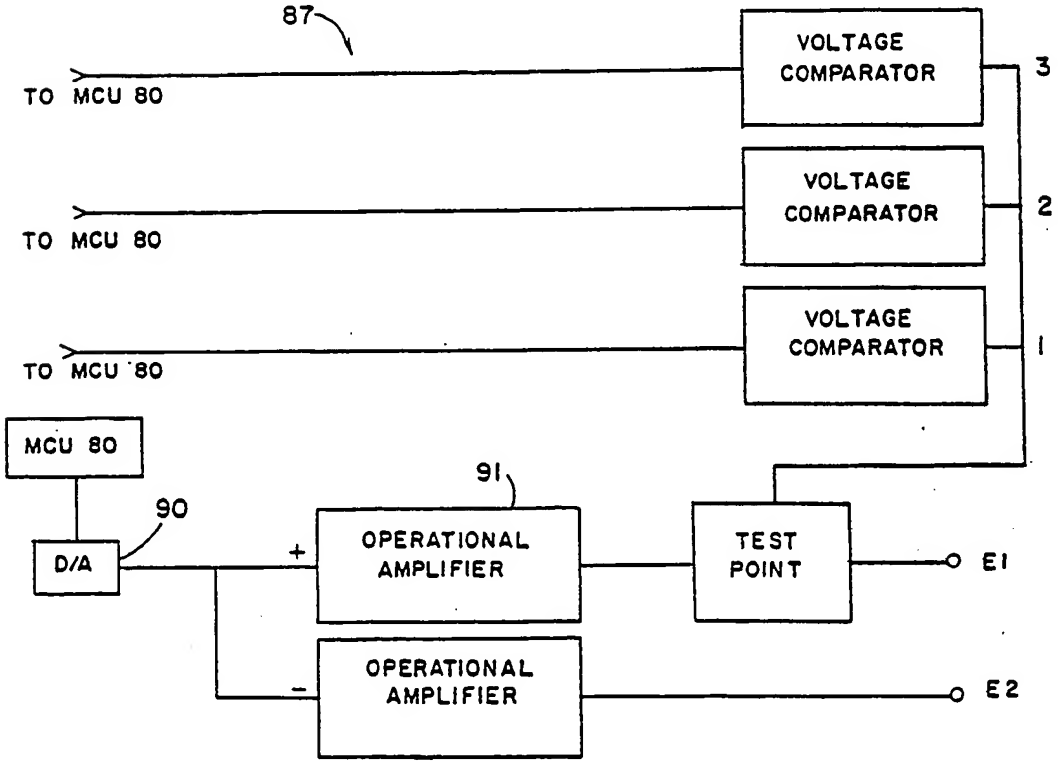

87
TO MCU 80
VOLTAGE COMPARATOR
3
TO MCU 80
VOLTAGE COMPARATOR
2
TO MCU 80
VOLTAGE COMPARATOR
1
MCU 80
91
90
D/A
+
OPERATIONAL AMPLIFIER
TEST POINT
E1
−
OPERATIONAL AMPLIFIER
E2

FIG. 10

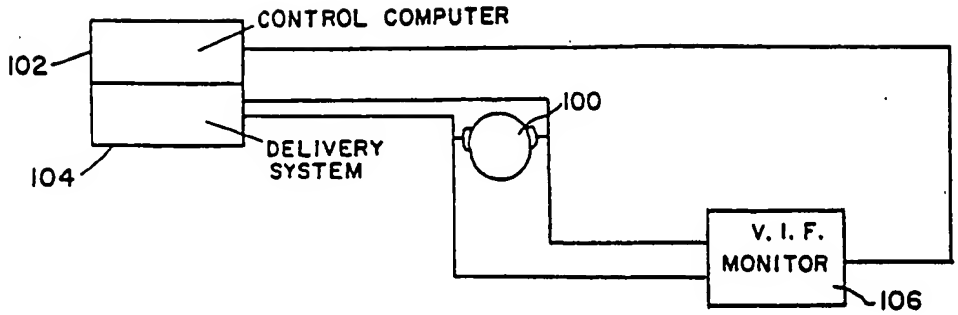


FIG. 11

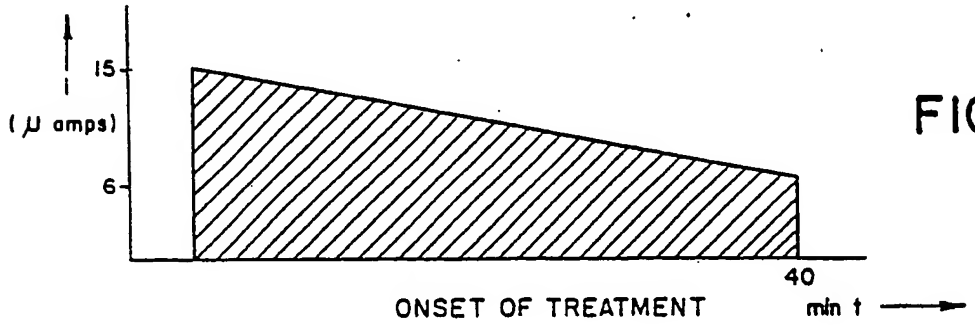


FIG. 12

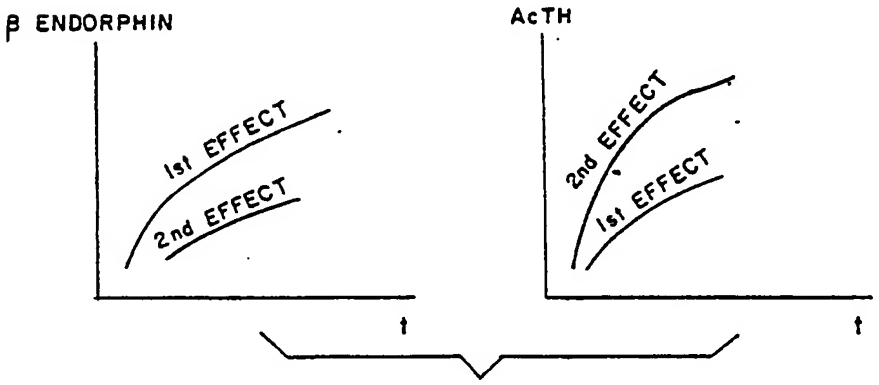


FIG. 13

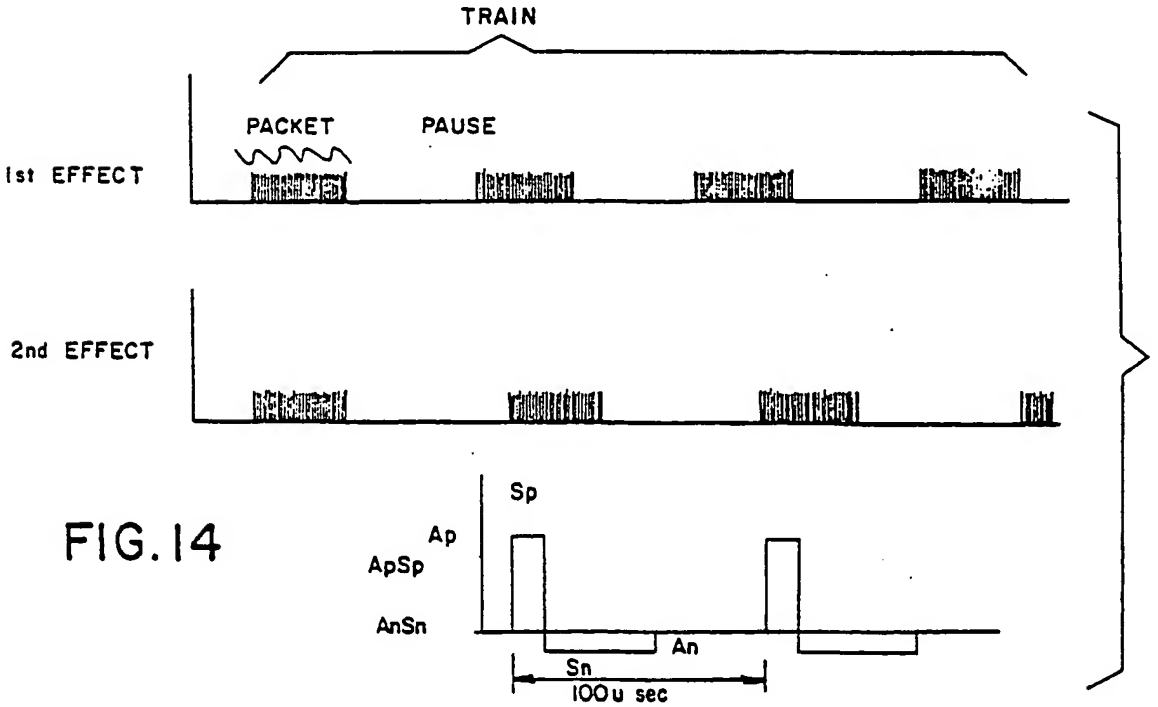
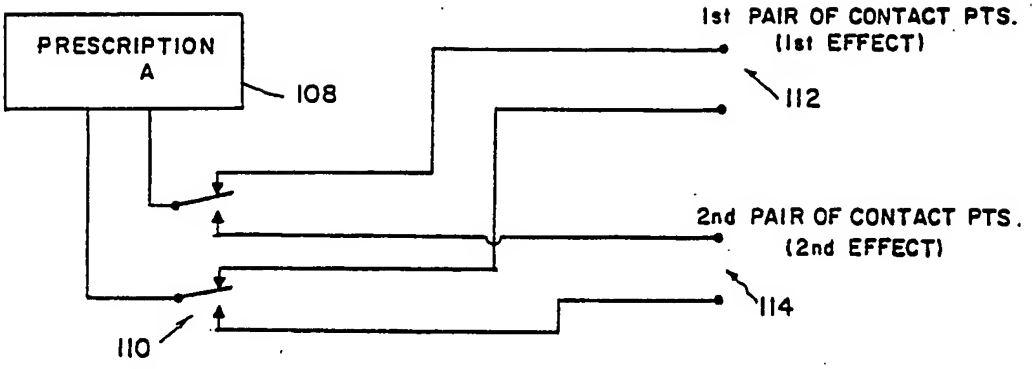


FIG. 14

FIG. 15


PRESCRIPTION A
108
1st PAIR OF CONTACT PTS. (1st EFFECT)
112
2nd PAIR OF CONTACT PTS. (2nd EFFECT)
114
110

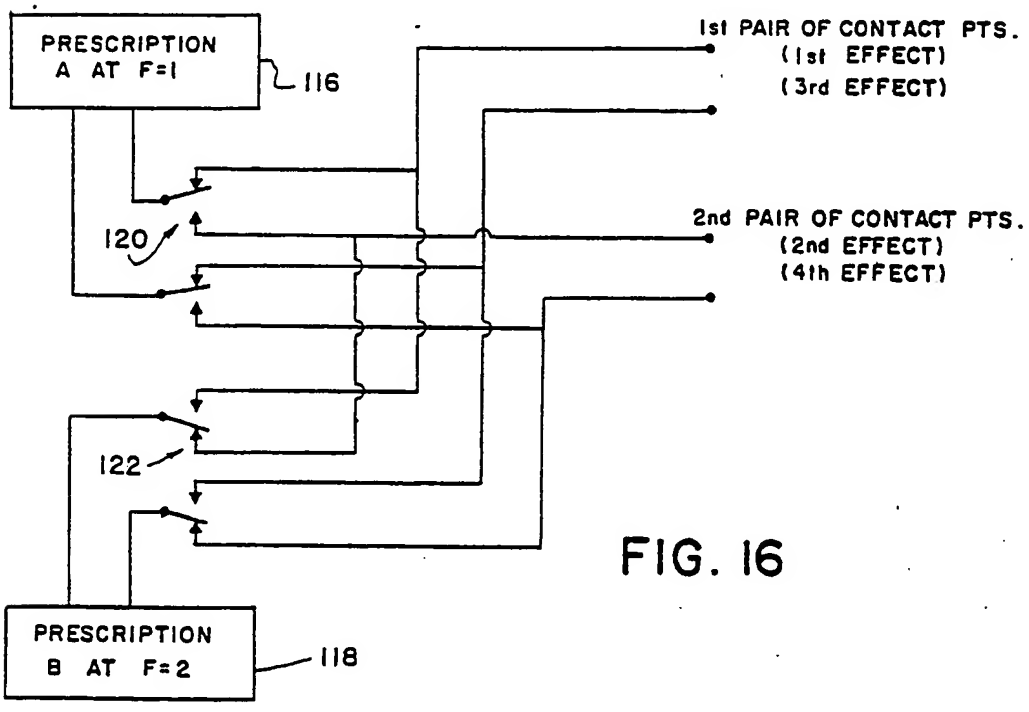

PRESCRIPTION A AT F=1
116
1st PAIR OF CONTACT PTS. (1st EFFECT) (3rd EFFECT)
2nd PAIR OF CONTACT PTS. (2nd EFFECT) (4th EFFECT)
120
122
PRESCRIPTION B AT F=2
118

FIG. 16

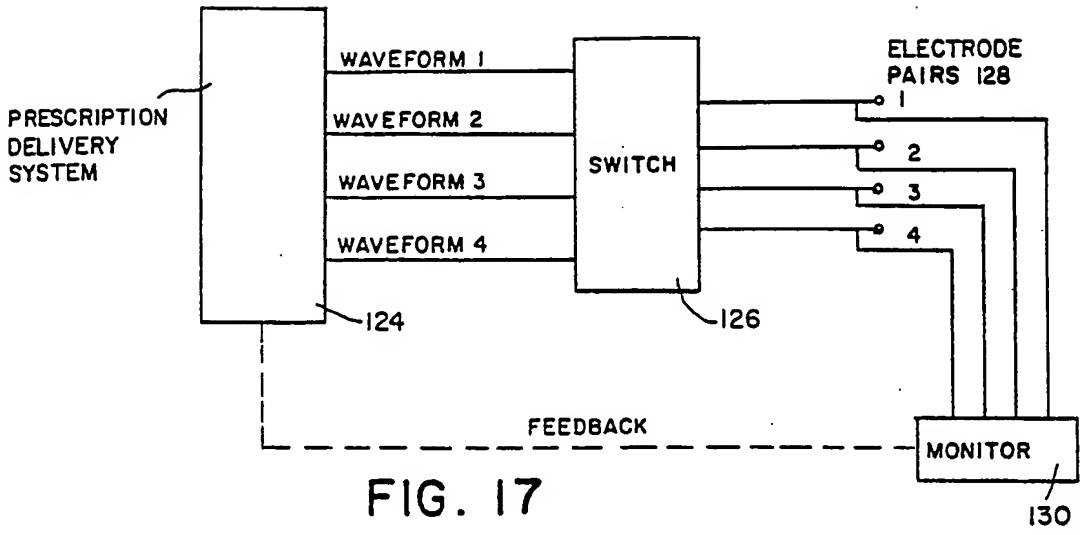

PRESCRIPTION DELIVERY SYSTEM
WAVEFORM 1
WAVEFORM 2
WAVEFORM 3
WAVEFORM 4
SWITCH
ELECTRODE PAIRS 128
1
2
3
4
124
126
FEEDBACK
MONITOR
130

FIG. 17

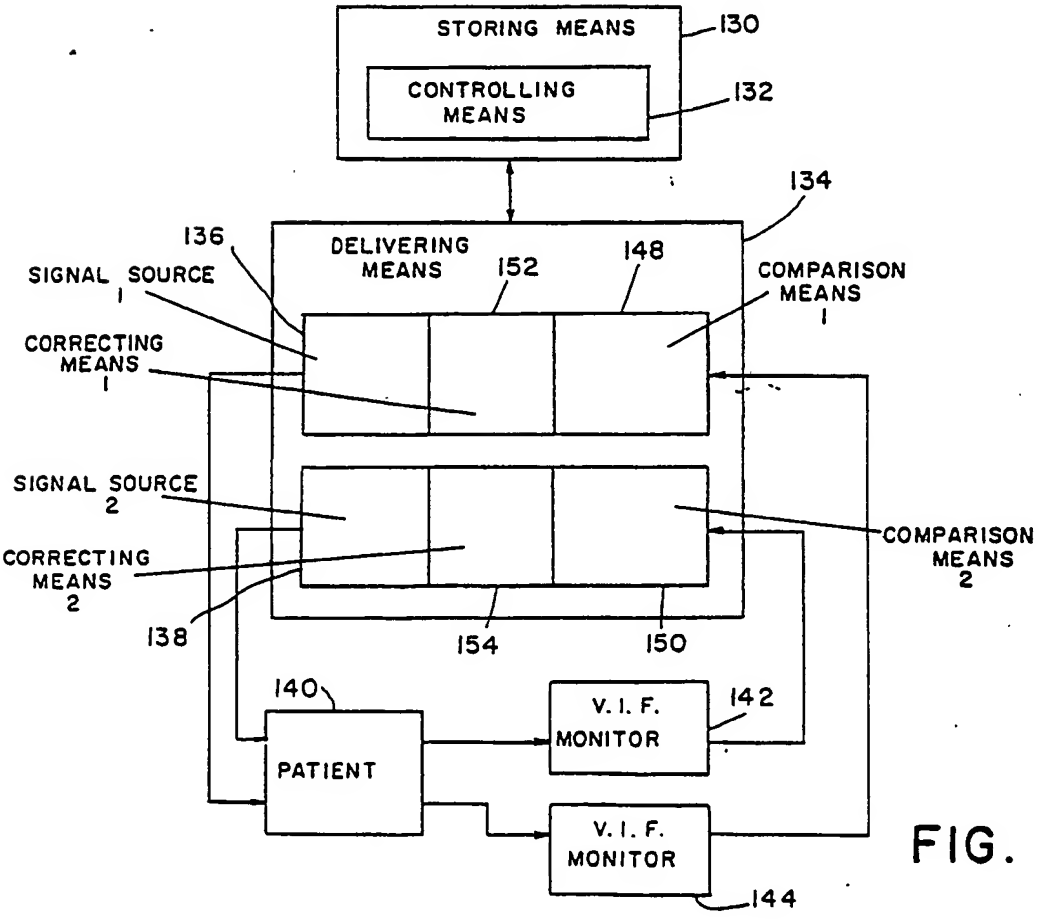

STORING MEANS
130
CONTROLLING MEANS
132
134
136
DELIVERING MEANS
152
148
SIGNAL SOURCE 1
COMPARISON MEANS 1
CORRECTING MEANS 1
SIGNAL SOURCE 2
COMPARISON MEANS 2
CORRECTING MEANS 2
138
154
150
140
V. I. F. MONITOR
142
PATIENT
V. I. F. MONITOR
144

FIG. 18

PCT

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(71) Applicant: ZION EDUCATIONAL FOUNDATION [GB/US]; 6555 North Mozart, Chicago, IL 60645 (US).

(72) Inventor: SKOLNICK, Malcolm, H. ; 733 Brogden Road, Houston, TX 77024 (US).

(74) Agent: VADEN, Frank, S., III; Vaden, Eickenroht, Thompson & Boulware, One Riverway, Suite 2420, Houston, TX 77056 (US).

(81) Designated States: AT (European patent), AU, BE (European patent), BG, BJ (OAPI patent), BR, CF (OAPI patent), CG (OAPI patent), CH (European patent), CM (OAPI patent), DE (European patent), DK, FI, FR (European patent), GA (OAPI patent), GB (European patent), HU, IT (European patent), JP, KP, KR, LK, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL (European patent), NO, RO, SD, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent).

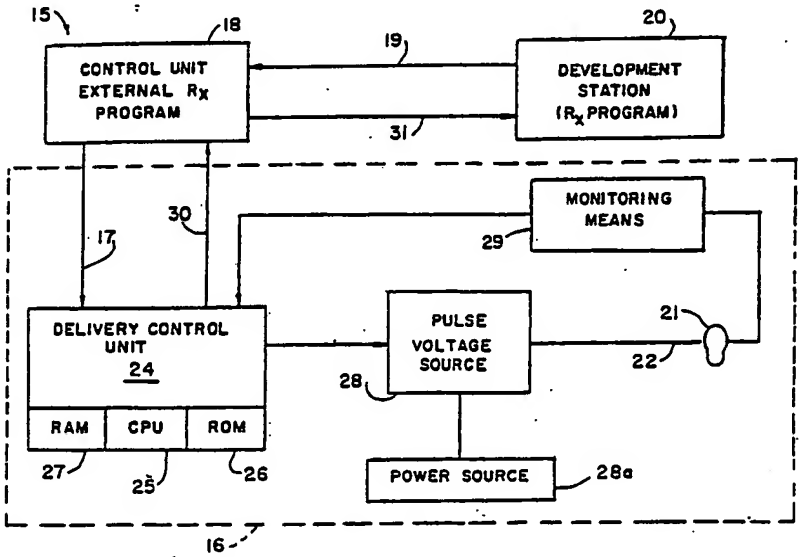
Published

With international search report.

Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(88) Date of publication of the international search report: 14 January 1988 (14.01.88)

(54) Title: METHOD AND APPARATUS FOR DELIVERING A PRESCRIPTIVE ELECTRICAL SIGNAL



(57) Abstract

Apparatus and method of transcranial electrical nerve stimulation including the generation of a reliable, reproducible, programmable, prescriptive waveform. The applied signal has a therapeutic effect which, depending on the prescription, ameliorates pain, assists in ameliorating stress or anxiety-related disorders, minimizes the withdrawal symptoms in drug detoxification and the like. The electrical signal is a continuous and interrupted complex of pulses and has a zero net cummulative charge. The preferred application of the prescribed signal is via selected contact points on the skin of the ear. The contact points are chosen because of their known affinity for changing endogenous concentrations of neurotransmitters and neuromodulators in the brain. The parameters of the electrical prescription include current amplitude, pulse width, zero net charge delivered in any pulse, time between adjacent pulses, number of pulses in a packet, the time between adjacent packets in a pulse train and the number of pulse trains in the prescription. Monitoring of the actual delivered signal to the patient is performed. The monitored response is used to correct system output to insure adherence with the signal parameters that are prescribed to optimize accuracy of signal application and therapeutic results.

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FI	Finland				

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 87/01438

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[4]: A 61 N 1/36

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC[4]	A 61 N

Documentation Searched other than Minimum Documentation to the Extent that such Documents are included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [10]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	DE, A, 3207050 (SIEMENS) 8 September 1983 see page 6, lines 6-23; page 8, line 25 - page 9, line 30; page 10, line 27 - page 11, line 13; page 11, lines 21-29; page 13, lines 3-12; figurs 1-3	1-4,8,10-13,16,19-23,26-28,39,42,45-47,49-51,61,62
X	WO, A, 86/02567 (ZION FOUNDATION) 9 May 1986 see page 9, line 16 - page 21, line 23; figures 1-10	1-4,7,9-33,36-50,55,56,60-62
X	EP, A, 0164016 (SYMTONIC) 11 December 1985 see page 14, line 18 - page 15, line 28; figure 1	31,32
A		26-28,36,50-54,57,59

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
2nd November 1987	1 DEC 1987
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	M. VAN MOL

International Application No. PCT/US 87/01438

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
Y	FR, A, 2191824 (CENTRE D'ETUDES POUR L'INDUSTRIE PHARMACEUTIQUE) 1 February 1974 see page 1, lines 21-39; page 3, line 21 - page 5, line 3; figures 1,2	1-4,19,24, 25,39,43
Y	US, A, 4167189 (TACHI) 11 September 1979 see column 1, line 49 - column 2, line 11; column 4, line 8 - column 6, line 40; figures 4,5	1-4,19,24, 25,39,43
A		8,15,22-24
A	US,A, 3727616 (LENZKES) 17 April 1973 see column 6, line 12 - column 7, line 19; column 8, lines 38-44; column 9, lines 6-47; figures 1,4,6	1,9,11-16, 18,20,21,37, 45,50
A	US, A, 4055190 (TANY) 25 October 1977 see column 2, line 55 - column 4, line 7; column 4, lines 24-57	1,6,7,9,13, 15,26,29,33, 56
A	US, A, 3900020 (LOCK) 19 August 1975 see column 5, line 57 - column 6, line 17; figure 4	1,23
A	US,A, 4112923 (TOMECEK) 12 September 1978 see column 7, line 45 - column 8, line 55; figures 3,11	1,7,15,17, 23
A	US, A, 4167190 (SORENSEN) 11 September 1979 see column 3, line 6 - column 4, line 23; figure 1	1,2,4,5,9, 11-16,18
A	EP,A, 0160753 (INT. MEDICAL MACHINES) 13 November 1985 see abstract; page 5, line 11 - page 8, line 2; figures 1,2	5-7,29,33, 36-38,40,54, 55,57-59
A	US,A, 4014323 (GILMER) 29 March 1977 see column 6, line 45 - column 7, line 23; figures 6,7	5-7,14,15, 17,47,48
A	US, A, 3718132 (HOLT) 27 February 1973 see abstract, column 5, lines 36-53; figure 7	8,9,34,35, 60
A	EP, A, 0011935 (MEDTRONIC) 11 June 1980 see the whole document	
P,A	US, A, 4646744 (CAPEL) 3 March 1987 see the whole document cited in the application	

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. [XX] OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This International search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. [X] Claim numbers XX, because they relate to subject matter not required to be searched by this Authority, namely:

XX Claims 32-49, 61,62
See PCT Rule 39.1(iv)
Methods for treatment of human or animal body by means of surgery or therapy, as well as diagnostic methods.

2. [ ] Claim numbers....., because they relate to parts of the International application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claim numbers....., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. [ ] OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. [ ] As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

- [ ] The additional search fees were accompanied by applicant's protest.
- [ ] No protest accompanied the payment of additional search fees.

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/US 87/01438 (SA 17972)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 14/11/87

The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
DE-A- 3207050	08/09/83	EP-A-	0087617	07/09/83
WO-A- 8602567	09/05/86	AU-A-	5062385	15/05/86
		EP-A-	0202258	26/11/86
		JP-T-	62501192	14/05/87
EP-A- 0164016	11/12/85	WO-A-	8505278	05/12/85
		JP-T-	61502236	09/10/86
		US-A-	4649935	17/03/87
FR-A- 2191824	01/02/74	NL-A-	7308773	28/12/73
		DE-A-	2331680	17/01/74
		BE-A-	801386	15/10/73
		US-A-	3869661	04/03/75
		CH-A-	570148	15/12/75
		GB-A-	1435996	19/05/76
US-A- 4167189	11/09/79	JP-A-	52131677	04/11/77
US-A- 3727616	17/04/73	None		
US-A- 4055190	25/10/77	None		
US-A- 3900020	19/08/75	None		
US-A- 4112923	12/09/78	None		
US-A- 4167190	11/09/79	None		
EP-A- 0160753	13/11/85	US-A-	4556064	03/12/85
US-A- 4014323	29/03/77	None		
US-A- 3718132	27/02/73	None		
EP-A- 0011935	11/06/80	FR-A,B	2441209	06/06/80
		DE-A-	2944542	14/05/80
		US-A-	4208008	17/06/80
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		AU-B-	533061	27/10/83

		US-A-	4236524	02/12/80
		JP-A-	55066370	19/05/80
		CA-A-	1138934	04/01/83
		US-A-	4305397	15/12/81
		US-A-	4250884	17/02/81
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